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Two-Inch and Four-Inch Food Cooling in a Commercial Walk-In Refrigerator

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SUMMARY

In 1976, the FDA food code *(4)* called for food to be cooled from hot to 45°F in 4 h. The FDA 1997 food code *(5)* recommends cooling from 140 to 70°F in 2 h and from 70 to 41°F in 4 h. Actually, if these times are to be achieved, energy-intensive, expensive blast coolers must be used. However, the industry has not been required to purchase them, except under rare circumstances. One reason that blast coolers are not required is that there is no adequate government procedure to measure the cooling of food in containers. Hence, during inspections, regulatory inspectors have been forced to estimate actual cooling rates in refrigerated food containers in retail food operations.

This study shows that food 2 in deep, in a covered pan, in a commercial walk-in refrigerator in a typical restaurant, takes over 10 h to cool from 130 to 45°F. If the food is 4 in deep, the cooling time is over 30 h.

Juneja, *et al. (6)* showed that 15 h cooling from 130 to 45°F is safe. The correct technique is presented for measuring food cooling in a food operation. If 4-h or 6-h cooling is to be enforced, then every inspector must have correct cooling knowledge, have the correct temperature measuring equipment, follow the testing procedure described in this study, and then, enforce the food codes. Otherwise, the ever-present cooling risk will not be controlled.

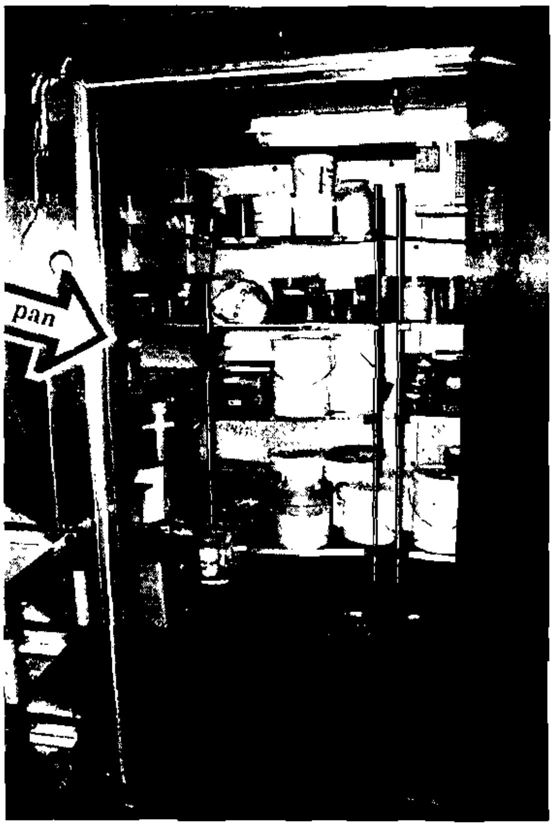
INTRODUCTION

In 1976, as a result of the investigative studies of Dr. Frank Bryan *(2)*, the FDA acknowledged that food cooling was the major cause of foodborne illness *(4)* and recommended that food in retail food operations be cooled from hot to 45°F in 4 h or less. However, no references were given for the 4-h requirement.

In the fall of 1990, at the Food Safety Technical Standards Workshop in Bethesda, Maryland *(13)*, it was learned that this recommendation was based on studies by Lewis, *et al. (7)* and Longrée and White *(9)*. Actually, these two studies and the study by Blankenship, *et al. (1)* are inappropriate to describe the cooling process and the subsequent microbiological safety of food. This problem was corrected by Juneja, *et al. (6)*. This study found that continuous cooling of food within 15 h from 130 to 45°F with a 38°F driving force controlled the outgrowth of *Clostridium perfringens*. *Clostridium perfringens* is the organism of concern, because in its spore form, it survives pasteurization in retail food operations.

In 1976, the author began the Minnesota HACCP Program for

Figure 1. Position of test pans in the refrigerator.



Retail Food Safety through Quality Assurance. Studies were conducted at the University of Minnesota, Department of Food Science and Nutrition, to determine how to achieve 4-h cooling. It was immediately evident that food could not be more than 2 in deep, 1 in center to surface. It was also apparent that cooling food 2 in deep in a covered, $2\frac{1}{2}$-in pan from hot (140°F or above) to 45°F in 4 h requires approximately 35°F air at a velocity of >1,000 feet per min (fpm) blowing across the pan of food. For more than 20 years, Victory, a refrigeration company, has had a rapid-chill refrigerator capable of cooling 200 lb of covered, 2-in-deep food to 45°F in 4 h. The air flow in this refrigeration system is >1,000 fpm, and the air temperature is about 28°F at the end of cooling to provide an adequate driving force *(8)*. If air at a lower temperature is used, the cooling rate is not increased to any extent, because ice forms in the outside layer of the food, and the center of the food encounters only a 32°F driving force.

Even though the 4-h cooling recommendation has existed since 1976, there have been no studies to determine adequate testing procedures to accurately perform cooling experiments to determine the actual, safe center-cooling temperature for a food container in a retail food operation. Evidence has shown that even food with a depth of 2 in in a pan takes mueh longer than 4 h to cool in a typical NSF International-certified foodservice refrigerator. Because of NSF International standards for compressor capability and evaporator fan velocity, most refrigerators and refrigeration systems are adequate only for storing food. If retail food operations had been forced to comply with the 4-h cooling recommendation, most retail food operations would have purchased blast coolers at a minimum cost of $9,000 each to achieve 4 h cooling.

The dual purpose of this research was to conduct simple cooling experiments to: (1) illustrate how to do a cooling study of food in a foodservice operation and (2) record the actual cooling times of food at depths of 2 in (in a $2\frac{1}{2}$-in pan) and 4 in (in a 6-in pan) in a typical retail food operation walk-in refrigerator in Minnesota. For many years, Minnesota has required a 40°F cold food temperature, rather than 45°F, as recommended by the 1976 FDA food code *(4)*.

THE MATHEMATICS OF COOLING

Pflug and Blaisdell *(12)* and Dickerson and Reader *(3)* provide thorough descriptions of the mathematics of the cooling process. The mathematics can be reduced to the following equations:

$$k\Delta\text{time} = \log(T\,\text{actual} - T\,\text{cold source}) \quad (1)$$
$$= \log(T\,\text{start} - T\,\text{cold source})$$

where k is the slope of the cooling line,

or

$$k\Delta t = \log(T\,\text{actual} - T\,\text{cold source})$$
$$= \log(T\,\text{start} - T\,\text{cold source})$$

To calculate the slope k of the cooling line, rewrite the equation as:

$$k = \log(T\,\text{actual} - T\,\text{cold source}) - \log(T\,\text{start} - T\,\text{cold source}) \div \Delta t \quad (2)$$

To find the actual product temperature after time, use

$$T\,\text{actual} = T\,\text{cold source} + (T\,\text{start} - T\,\text{cold source}) \times 10^{k\Delta t}. \quad (3)$$

To find the actual time to get to a temperature, use

$$\Delta t = \log(T\,\text{actual} - T\,\text{cold source}) - \log(T\,\text{start} - T\,\text{cold source}) \div k \quad (4)$$

This means that if the difference in temperature between the center of the hot food and the cold source, such as the air in the refrigerator or water in a cold water bath, is plotted on semilog paper, a straight line is achieved. The bottom point on the y axis is chosen as 1°F above the cold source temperature, because, in principle, the center of the food can only approach the temperature of the cold source but will never actually reach the temperature of the cold source, as evidenced by the above equations.

Figure 2. $2^1/_2$-in pan in position.

Figure 3. 6-in pan in position.

METHODS AND MATERIALS

This experiment was conducted in a commercial full-service restaurant in Minnesota. The kitchen and walk-in refrigerator are 12 years old. This facility and equipment have been inspected regularly by the local sanitarian and have passed inspection. The walk-in refrigerator in which the study was conducted is 7 ft high × 16 ft wide × 6 ft deep. There is a 3-fan blower in the middle of the refrigerator. Figure 1 is a photograph of the inside of the refrigerator showing how the test pans were positioned (center of picture) on a shelf. Figure 2 is the $2^1/_2$-in pan in position. Figure 3 is the 6-in pan in position.

The air flow was measured with a Sierra Instruments Model 441 meter (Carmel Valley, CA). Air flow was measured with the respective pans in place, in the center, approximately 1 in below and 2 in above each pan. Temperatures were recorded with a Barnant Model 600-1050 dual-channel meter (Barrington, IL) set to provide logging at 10-min intervals. Temperatures were recorded to 0.1°F. Type K 24-gauge thermocouple wire was used to measure the temperature in the middle of the food and the temperature of the air 4 in above the food pan. The thermocouple was held in place by a $^1/_8$-in wooden dowel. Figure 4 shows the device used to hold the thermocouple in place. The thermocouple in the food was placed either 1 or 2 in above the end of the dowel, depending on whether the 2-in or 4-in deep food was being measured. The dowel rested on the bottom of the pan, so that the thermocouple junction would be exactly 1 or 2 in, respectively, from the bottom of the pan. Each pan was supported 4 in off of the solid shelf by $^1/_8$ pan inserts. If the pan had been placed directly on the shelf, there would have been additional thermal resistance from the bottom of the pan, and it would be expected that the cooling time would almost double. The author's

Figure 4. Fixture holding the thermocouple.

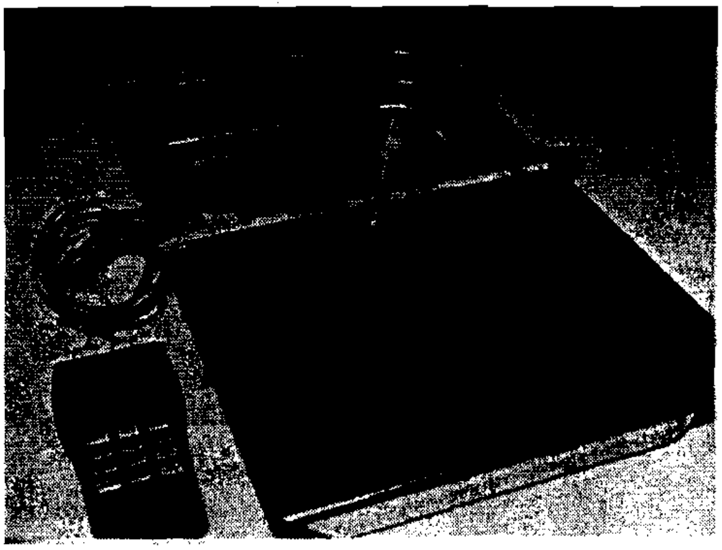
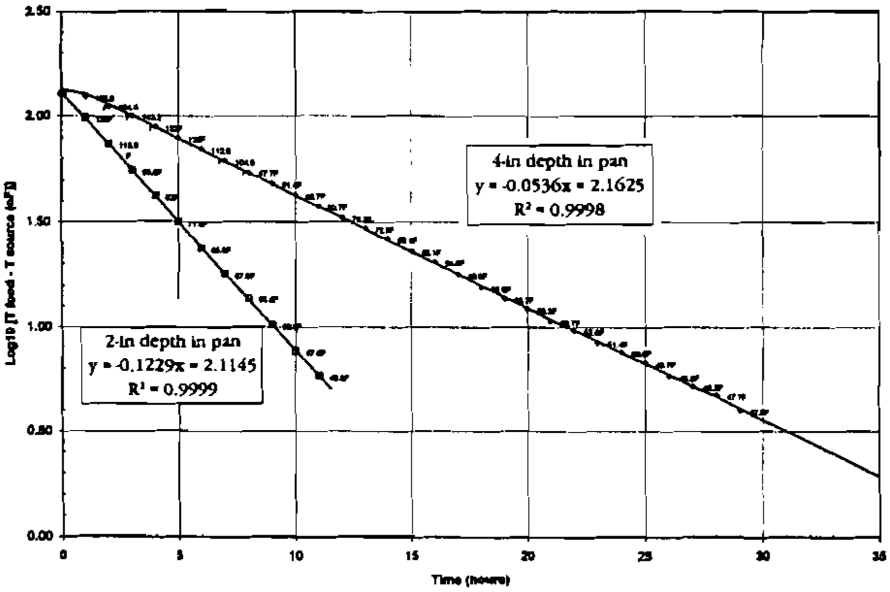


Figure 5. Food cooling (2-in depth in pan compared to 4-in depth in pan).



previous experiments have shown that about 75% of the heat is removed through the bottom of the pan.

The food cooled in this study was a gelatinized starch mixture (water and flour), which is essentially a gravy without flavor. A volume of 7 quarts filled a $2^1/_2$-in × 12-in × 20-in pan to 2 in; 14 quarts filled a 6-in × 12-in × 20-in pan to 4 in. To prepare the gelatinized starch mixture, about 80% of the water was put on the stove and heated to boiling; the other 20% of the water was cold and was mixed with a flour at a ratio of 7% weight of flour to weight of total water. The cold flour-water mixture was added to the boiling water and stirred for approximately 3 min, at which time it fully thickened to its ultimate viscosity. This gelatinized starch mixture, which has a specific heat of about 1 Btu/lb°F, was used for a cooling study to eliminate convective heat transfer. If convective heat transfer is not eliminated, the food cools almost twice as fast. The pans containing the gelatinized starch (flour and water) mixture were covered with aluminum foil so that there would be minimal loss of steam and hence, minimal evaporative cooling. (Cooling of surfaces through evaporation accelerates cooling and produces false data.) The pans were placed in the refrigerator, and the logging process began.

RESULTS

The results of the cooling tests on the covered gelatinized starch (flour and water) mixture at the 2-in and 4-in depth are shown in Figure 5 and Tables 1 and 2. In the case of the 2-in food cooling, the time to reach 45°F was 11 h, 30 min, approximately. The time for the food to cool from 130 to 45°F was about $10^1/_4$ h. Because the driving force air temperature averaged about 40°F, the calculated time to reach 41°F would have been 16 h. Cooling time is extremely dependent on the air flow across the pan, which in this case, fluctuated between 30 to 50 fpm underneath the pan and 100 fpm across the top of the pan. At an air flow of approximately 1,000 fpm, food cooling time is cut to $^1/_3$ the time of food cooled in an air flow of 50 fpm. Hence, this 11-h, 30-min cooling would be approximately 4-h cooling if there had been a fan blowing air directly across the pan.

The graph and tables (Figure 5, Tables 1 and 2) for the covered, 4-in food cooling show that at 29 h, when the cooling was stopped, the center temperature of the food was 47°F. Had the study continued until the center temperature reached 45°F, the time would have been close to 35 h. Figure 5 shows that the time to cool food from 130 to 45°F is about $30^3/_4$ h. Because the effective average air temperature of the refrigerator was about 43°F, this food would never have reached 41°F.

TABLE 1.

Time	2-in food cooling		
Hours	Temp. °F	Temp. –40°F	Log Temp. –40°F
0	171.3	131.3	2.12
1	138.3	98.3	1.99
2	113.9	73.9	1.87
3	95.6	55.6	1.75
4	82.0	42	1.62
5	71.6	31.6	1.50
6	63.6	23.6	1.37
7	57.9	17.9	1.25
8	53.8	13.8	1.14
9	50.2	10.2	1.01
10	47.6	7.6	0.88
11	45.8	5.8	0.76

The apparent effective driving force (air temperature) is developed from the experimental data, because the walk-in refrigerator compressor is cycling, and the air temperature is not stable. The on-off period for the compressor on the refrigeration system used in this study was approximately 40 min (data not shown). The compressor turned on when the air temperature inside the unit reached approximately 45°F and turned off when it reached 38°F. The food in the refrigerator acts as a "fly wheel" to stabilize the refrigerator temperature. When the compressor is on, the food loses heat and gets colder; when the compressor is off, the food helps to keep the refrigerator cold.

DISCUSSION

The author has been conducting similar experiments since 1976 and teaching operators throughout the U.S. how to cool food. The results of all of these studies have been typical of this test. In Minnesota today, there is a requirement for 4-h cooling to 40°F because of a decision made 40 years ago to set Minnesota cold food holding at 40°F *(10)*. Actually, many sanitarians in Minnesota know the results of the author's studies over the past 20 years.

The results show that no commercial NSF International refrigerator will cool food 2 in deep in 4 h, according to the FDA 1976 code *(4)*, or from 140 to 70°F in 2 h and 70 to 41°F in 4 h, according to the 1997 food code *(5)*. If the FDA code or cooling recommendations were strictly enforced, every operator in Minnesota would be required to purchase a blast cooler at a cost of at least $9,000. No epidemiological evidence has shown that anyone becomes ill from food cooled 2 in deep in a covered pan in a normal NSF International foodservice (storage) refrigerator.

Some sanitarians say that food should remain uncovered during cooling. It is true that if food is left uncovered, it cools more rapidly. However, it will also become contaminated with mold from the fan blades and the refrigerator coil. Although NSF International listed, the fans and coils are basically uncleanable in walk-in or reach-in refrigerators. They become extremely contaminated with high levels of bacteria, such as *Listeria monocytogenes*, and with mold.

Food can also be cooled in pots and buckets in an ice bath. When food is cooled in this manner, it must be stirred almost constantly. In addition, the ice water must also be agitated to assure that 32°F water is next to the container, because heat transfers from the outside of the container. The safe, simple answer for cooling food without large labor costs is to cool food 2 in deep in a covered container in a refrigerator.

The author has found that it is not necessary to spend a lot of money on a blast cooler to achieve a 4-h cooling rate if the code were to be enforced. A simple, $12.00 box fan (which can be purchased at a discount store) blowing air directly across the food, is adequate, if the food is on a rack so that the bottoms of the pans are exposed to the blowing air. However, the research of Juneja, *et al.* *(6)* has shown that 4- or 6-h cooling is unnecessary. If a fan is combined with the 15-h safety limit, a major advantage is that food 4 in deep, and 5-gallon buckets of sauce, for example, can be cooled safely. The fan increases the cooling rate by a factor of three. Therefore, if food with a depth of 4 in in a pan takes about 30 h to cool in a standard refrigerator, it will cool safely in 10 h. The 5-gallon bucket of food will cool in about 15 h (unpublished data).

The gelatinized starch (flour and water) mixture used in this study is the correct food simulator to use for this kind of study, because it is very inexpensive and is a very difficult food product to cool. It is so viscous that the only type of heat transfer during cooling is conduction. Water has the highest specific heat of any food

TABLE 2.

Time	4-in food cooling		
Hours	Temp. °F	Temp. –43°F	Log Temp. –43°F
0	173.9	130.9	2.12
1	166.5	123.5	2.09
2	154.8	111.8	2.05
3	143.2	100.2	2.00
4	132.0	89.0	1.95
5	122.0	79.0	1.90
6	112.9	69.9	1.84
7	104.8	61.8	1.79
8	97.7	54.7	1.74
9	91.4	48.4	1.68
10	85.7	42.7	1.63
11	80.7	37.7	1.58
12	76.2	33.2	1.52
13	72.5	29.5	1.47
14	69.4	26.4	1.42
15	66.1	23.1	1.36
16	63.6	20.6	1.31
17	60.9	17.9	1.25
18	58.5	15.5	1.19
19	56.7	13.7	1.14
20	55.2	12.2	1.09
21	53.7	10.7	1.03
22	52.6	9.6	0.98
23	51.4	8.4	0.92
24	50.6	7.6	0.88
25	49.7	6.7	0.83
26	48.8	5.8	0.76
27	48.2	5.2	0.72
28	47.7	4.7	0.67
29	47.0	4.0	0.60

item. Hence, the gelatinized starch (flour and water) mixture thickened with a 7% flour-water mixture at about 190°F makes this test the correct one for a HACCP test of refrigeration in actual restaurant operations.

The chemical properties of the food also affect the outgrowth of *C. perfringens* and hence, the necessary cooling rate to keep the food safe. The cooling study by Juneja, *et al. (6)* was done on hamburger media, which is optimum for the growth of *C. perfringens*. If this study were done on tomato-based products or sauces with wine and fruit, which have much lower pHs in the range of 4.3 to 5.2, the outgrowth of *C. perfringens* would be significantly limited, if not prevented, and safe cooling times would be much longer than the 15 h for hamburger.

CONCLUSIONS

This study summarizes two simple experiments to show the correct way to perform a cooling study and to evaluate the effectiveness of cooling in retail food operations. It is also appropriate for home refrigerators. It presents the materials and methods that provide a consistent cooling test result each time. The cooling experiment is very easy to do. NSF International Standards 4 and 7 *(11)* still do not deal correctly with cooling in retail food operations. In addition, these NSF standards can be reproduced only in a laboratory and do not predict performance in actual operations. The procedure described in this study can be used to provide full validation of HACCP cooling in a retail operation.

It is time now, in 1997, after almost 20 years, to begin accurately measuring the temperature of food cooling and to determine accurately what is necessary for safe cooling and what rate is actually needed for each food item, based on its ingredients and microbiological growth hurdles. Depending on the ingredients, the outgrowth of *C. perfringens* will vary, and safe cooling times can be much longer.

Clostridium perfringens is a very common food contaminant. It survives normal pasteurization; its spores outgrow to high levels in food *(14)*. Before the FDA publishes cooling recommendations, it should be able to accurately show the relationship between spore outgrowth, pH, and other parameters. In this way, the retail food industry can avoid spending money on blast coolers when these devices may not be necessary to improve the safety of food products.

Much research remains to be done. The retail food industry, as it institutes HACCP self-control, must solve the problem of correct cooling and provide correct data tables for cooling throughout the U.S. This will allow operators maximum, yet safe, food cooling times.

There have been many cooling rules and regulations written by sanitarians throughout the U.S. since 1976, and much imprecise information based on these rules and regulations has been given to the retail food industry. Each government food inspector must learn how to measure food cooling correctly in food operations and be provided with the necessary, accurate instruments to perform cooling evaluations if food inspections are to effectively monitor cooling risk.

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